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15-12/03 Christian Roscher-Nielsen Email: Christian:dnva.no

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Norway and the International Polar Year 2007-08

Input from the Norwegian National Committee on Polar Research

1. Introduction

The present report is based on a national workshop held in Tromsø 3-4 November 2003 arranged by the Norwegian National Committee on Polar Research. About 50 scientists from Norwegian institutions discussed national science priorities for IPY. The report is presented to the Norwegian Academy of Science and Letters, who will formally submit the Norwegian interests in the participation in IPY to the ICSU IPY-Planning Group.

The first part of the workshop included presentations of relevant research questions within different scientific disciplines. In the second part, the participants split into five working groups:
1. Biology
2. Climate processes and effects – atmosphere
3. Climate processes and effects – ice and ocean
4. Paleoclimate, geology and geophysics
5. Observations and technology

In this report, the main research themes identified by the groups are summarized. The individual working group reports are appended to the report.

Norway has long traditions in polar research within a broad range of disciplines. Basic research was the main focus in the past, but recently more applied aspects have gained importance. A major part of the Norwegian polar research has been conducted in Svalbard and the Nordic Seas. A major build up of research infrastructure has taken place in Svalbard in recent years, which might be useful for field campaigns during IPY. Norwegian logistic platforms in the Antarctic are also improving, and the Troll field station in Dronning Maud Land will be available as an all-year facility for the use during IPY. Use of these types of infrastructure will be a contribution by Norway to the international research community during IPY.

2. Main research issue

The Norwegian research community is interested in participating in several scientific activities related to an internationally coordinated effort through IPY. A major scientific issue of interest to Norwegian scientists relates to the role of the polar regions in global change and the effects of global change on nature and society. IPY represents the spectacular and unique opportunity to facilitate these research objectives through a dedicated and intensive field campaign. Focus on field experiments that can give IPY an identity and provide new data that can only be achieved through a co-ordinated international programme. Norway emphasizes that the proposed science will provide a long-term legacy for IPY.

Rationale

Although studied for more than 100 years, the polar regions still represent a scientific frontier in natural sciences. Due to its harsh and in hostile environment, modern technologies used for exploring and investigating the physical, geological, chemical and biological processes have only been used in a limited extent. Compared to other parts of the Earth, our understanding is limited with respect to its natural environment. Due to the growing understanding of possible future climatic changes, a better understanding of the polar regions is crucial. Reasonable scenarios of change in climate and human activities suggest that there may be major future changes in arctic ecosystems and, hence, human society. The importance of the polar regions for the world climate is strongly related to their positions for global cooling of the oceans as well as the lower atmosphere. The situation has however not been stable. This is in particular the case for the Arctic Ocean, which in a rather short geological time span has been transform from a warmer ocean to its present cold. From a scientific viewpoint, it is of uttermost importance to understand the evolution of the Arctic Ocean, and its surroundings as a background for understanding its present settings, ecosystems and resources. This is of particular importance due to the suggested extreme sensitivity to changes in its boundary conditions. The study past climatic conditions and ecosystems and their variations in the polar regions, provides a better understanding of the basic process and mechanisms controlling the arctic environment and its sensitivity to future changes.

Overarching scientific issue:

The role of the polar regions in global change – climate processes and effects – past, present and future

"Aims at a capability for detecting and predicting climate change and effects on decadal to centennial time scales"

The overall goal of this research issue is:

- *A quantum leap in our understanding of the role of the polar regions in the global climate system and their sensitivity to change*

- *Increase public awareness of the importance of polar processes for climate, weather and environment at middle and low latitudes as well as global well-being*

Under this umbrella Norway has identified research themes of high importance (see appendices for more details):

Theme 1: Understanding the dynamic processes of the polar oceans, land and atmosphere, including the energy and biogeochemical fluxes between the spheres

- **Determine past and present modes of thermohaline circulation (THC) and the climate/dynamic thresholds activating modal shifts**
- **Atmospheric dynamic process studies in polar regions**
- **Sea-ice and glaciers, the causes and effects of albedo changes, "the blue Arctic Ocean"**
- **Biogeochemical cycles and their response to climate change**

Theme 2: Exploring the evolution of the Arctic Ocean from a warm to a cold state

- **Ocean gateways – and the evolution of polar ocean connectivity**
- **Initiation and history of cryosphere and sea-ice**

Theme 3: Climate change and polar ecosystems

- **Islands of Arctic Life**
- **Ecosystem Function of the Arctic Ocean**
- **The human dimension; a circumpolar social science study**

3. Other main issues

3.1 Observations and technology

Current activities will not provide the critical mass to solve key questions for the IPY. The answer is to use IPY as a concerted international campaign to acquire the necessary data in programs based on large-scale, tightly coordinated comparative studies. Making simultaneous, circum-Arctic measurements would be a "spectacular" aspect of IPY.

Research stations

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- A network of research stations is available. These stations can be shared by many different disciplines, such as oceanography, glaciology, biology and atmospheric science. Such a network would

allow for data collection on a much denser grid for the duration of IPY 2007-8. In addition the countries participating in IPY should seek to strengthen their instrumentation at existing sites.

Mobile installations and satellites

- Co-ordinated use of information from satellites and the use of mobile installations (e.g. ships, aircrafts, buoys, floats, moorings). A special focus on the integration of satellite data with surface-based data and quantifying limitations of the capabilities of the various data sets is essential.

New technology

There are several important climate processes at high latitudes which need to be better quantified and understood. Key issues are increase in air temperature in the Arctic, reduction in sea ice cover and thickness, increased freshening and warming in subpolar seas, and changes of the Atlantic thermohaline circulation. There is a consensus among 19 global climate models that the greenhouse warming will be enhanced at high Northern latitudes. There are, however, large discrepancies between the models suggesting that the model results for high latitudes need to be carefully validated against observations. Better quantification of the changes is required and can only be obtained from better observing systems implemented through long-term monitoring programmes.

We propose to use the IPY as a vehicle to develop long term, cost-effective automated systems with real-time data transmission systems to facilitate easier access to data from the polar regions.

Examples are:

- deployment of an array of ice buoys in the central Arctic with more advanced instrumentation than the present IABP buoys. This array should drift for 2 – 3 years and send data in real-time, enabling real monitoring of the atmospheres, sea ice and ocean across the Arctic
- a subsurface sound source system for the Arctic would be yet another “spectacular” possibility for the IPY.

3.2 History of IPY

The previous IPY’s (and IGY) have had a significant impact on the development of polar science and international collaboration. Writing the history of IPY with emphasis of these themes would be a useful complement to the proposed research activities for IPY 2007-08.

4. General considerations

- Norway should play a lead role in overall project design as well as contribute towards sub-projects in IPY.

- Svalbard should act as a gate for the science community to arctic research.
- One should aim at developing the research facilities in Ny-Ålesund, Svalbard further and upgrading the Antarctic station Troll to international reference stations with a longer time horizon than just IPY.
- Work is needed to assure better access to polar data.
- The need to strengthen the collaboration with Russia.

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Appendix: Working group reports

1. Biology

Polar environments provide unique opportunities for exploring:

1. Frontiers in modern life sciences such as the fundamentals of adaptation and functioning of organisms and ecosystems.
2. The consequences of global change in terms of climate and pollutants.

We propose two programs; one terrestrial and one marine that will exploit these opportunities. They are eminently suitable and feasible in the context of the IPY and the strength of Norwegian biological science.

1.1 Islands of Arctic Life

Rationale and research topics:
Island studies have since the age of Charles Darwin been instrumental for understanding *organismic evolution* and *ecosystem organization*. This is because islands provide simple and transparent settings in terms of restricted size and range of habitats, gene - and species pools. Indeed, island organisms and ecosystems possess attributes that make them suitable *model systems* for exploring new fundamental questions within many biological sub-disciplines.

Island of sufficient size to harbour terrestrial species and ecosystems are found throughout the arctic rim oceans. Although the biology of some islands is well-known, for instance Spitsbergen, islands studies usually belong to the "cult of the isolated study". This is despite that a major potential of island studies lies in well-planned cross-island comparisons. Arctic islands, range from being among the most pristine places on the earth to some of the most anthropogenically disturbed, thus facilitating studies of *the effect of anthropogenic disturbances* on organisms and ecosystems. Island ecosystems also range vastly in terms of ambient light and climatic conditions and past history, thus facilitating analyses of the degree of *responsiveness of species and ecosystem function to climate and climate change*. Under some climate warming scenarios truly arctic species and ecosystems are likely to persist only on high arctic islands, because the northernmost land areas are islands and ocean barriers hinder invasion of southern species and ecosystems. Islands may therefore provide some of the last refuges for arctic biota. It is thus imperative that we soon are able to document *the basic adaptations of species and functioning of ecosystems* on these islands, and their *vulnerability to environmental change* including pollutants, tourism, climatic parameters and invasions of alien species.

Implementation:

Cross-island comparisons cannot presently be done because many islands are practically unstudied and because the different aims and methodologies of previous island studies usually prohibit meaningful analyses. We therefore envision a pan-arctic project based on sea - and air-born campaigns to access a number of islands widely distributed throughout the arctic oceans and where sampling, measurements and experiments adhere to a fixed set of aims and study protocols. The selection of islands to be included in the project will be based on the main research topics to be addressed, for instance, selecting islands across gradients of climate, light regimes and biogeographic/historical contexts. Mainland sites may be included for comparative purposes, as well as controlled experimental studies in laboratories throughout the arctic. Field work both in summer and winter will be warranted.

Relevance for IPY:
The proposed project intersects with several of the science themes and sub-themes proposed by ICSU such as frontier issues in evolution, genomics, biodiversity and ecosystem function and urgent issues concerning global change. A program based on large-scale, tightly coordinated, cross-island comparative studies that involves many biological sub-disciplines (e.g. physiology, evolutionary biology, paleo-biology, eco-toxicology and ecology) and potentially other natural sciences as well (geology, climatology), is a big enterprise. It requires broad international participation and funding as well as access to many localities, which normally are not accessible. For this reason we think an IPY-initiative is the only way for such an enterprise to be launched.

1.2 Ecosystem Function of the Arctic Ocean

Rationale and research topics:
The Arctic Ocean is among the least investigated parts of the world oceans. It plays, however, a global role in surface heat balance and thermohaline circulation. Polar marine ecosystems are greatly influenced by sea ice, and the presence of sea ice directly or indirectly affects the physical, chemical, and biological processes in the Arctic Ocean as well as in the Antarctic. Ice is also affected by local, regional, and global changes in climate at different time scales. Therefore, sea ice can be seen as a lever through which changes in climatic regimes can have far-reaching consequences on the structure and function of polar marine ecosystems. The proposed program therefore includes two aspects: one is to increase our general knowledge of the Arctic Ocean which is poor; the second is the possible effects of rapid climatic changes in the Arctic Ocean. This program focuses on the Arctic Ocean. A comparative study between Arctic and Antarctic ecosystem will be even more challenging.

Some of the most pronounced effects of global climate change will probably occur in polar regions, and sea ice is obviously susceptible to changing long-term average temperatures. The polar ice pack in the Arctic will probably decrease and the ice edge will consequently retreat northwards. The retreat will result in a profound widening of the marginal ice zone and result in an

extensive, stratified area that stretches from the Barents Sea shelf deeply into the Arctic Ocean. This situation would be a radical change from the present situation, fundamentally altering local ecosystem characteristics and processes in several regions of the Arctic Ocean. The weakly stratified conditions that are characteristic of the central Barents Sea to day will spread northwards. Temperature will increase, the distribution of Atlantic species will spread northwards and new production will probably increase. The low productivity in presently ice-covered waters in the north will turn into a stratified marginal ice zone with nutrient depletion after a short, intense ice edge bloom.

Implementation:
The Arctic Ocean is one of the least studied world ocean. We therefore envision a project based on sea - and air-born campaigns into the Arctic Ocean where sampling, measurements and experiments adhere to a fixed set of aims and study protocols. The selection of /study areas/cruise tracks will be based on the main research topics to be addressed, for instance, selecting gradients of climate, light regimes, seasons and biogeographic/historical contexts.

Relevance for IPY:
The proposed project intersects with several of the science themes and sub-themes proposed by ICSU such as frontier issues in biodiversity and ecosystem function and urgent issues concerning global change. A program based on cruises into the Arctic Ocean that involves many biological sub-disciplines (e.g. physiology, paleo-biology, and ecology) and potentially other natural sciences as well (geology, climatology), is a big enterprise. It requires broad international participation and funding as well as access to many localities, which normally is not accessible. The suggested program also opens for challenging comparisons between Arctic and Antarctic ecosystems. We think an IPY-initiative is the only way for such an enterprise to be launched.

2. Climate processes and effects – atmosphere

Overall goals

- A quantum leap in our understanding of the role of the polar regions in the global climate system and their sensitivity to change
  - Atmospheric dynamic process studies in polar regions
  - The causes and effects of albedo changes
  - Biogeochemical cycles and their response to climate change
  - Quantify exchange processes between spheres
- Increase public awareness of the importance of polar processes for climate, weather and environment at middle and low latitudes as well as global well-being.

General strategy

- One should plan the use of a relatively large number of mobile stations that can be placed in the Arctic and/or Antarctic region. These stations can be shared by many different disciplines, such as oceanography, glaciology, biology and atmospheric science. Such a network would allow for data collection on a much denser grid for the duration of IPY 2007-8.
- The density of the network and temporal resolution of the data should be designed to allow determining the representativeness of the existing stations and quantify (maybe even discover) key processes that are unresolved by the current network.
- A special focus on the integration of satellite data with surface-based data and quantifying limitations of the capabilities of the various data sets is essential.
- Modelling and field work must be integrated to ensure clever choices of IPY stations as well as enlightened decisions (at the end of IPY) regarding which new stations that should be retained for future monitoring and research efforts.

General considerations

- Norway should play a lead role in overall project design as well as contribute towards sub-projects as outlined below.
- Svalbard should act as a gate for the science community to Arctic research.
- One should aim at developing Ny-Ålesund further and upgrading Troll to international reference stations with a longer time horizon than just IPY.
- Work is needed to assure better access to polar data.
- The human dimension:
    - There is a need for a circumpolar social science study
    - Need for a better understanding of the economy in the Arctic region
- We need to collaborate with Russia. They have closed down many stations during the last decade or so, and some of these should be re-opened.

2.1 Polar climate

What is the problem?

The polar climate is important per se and because it influences the global climate system. We therefore need to understand the couplings sea/ice – troposphere – stratosphere in more details than we do today in order to model future climate change properly. In that respect, a better understanding of clouds and precipitation processes at very low temperatures are crucial in modelling possible climate changes. Other poorly understood processes that are crucial for a proper modelling of the Arctic climate are the role of the hydrological cycle and the role of possible permafrost melting in enhancing the greenhouse effect by release of greenhouse gases. Heat, water and momentum transfer between the surface and the atmosphere are another important process that is far from trivial in the Arctic with its (broken) ice-coverage. Climate change processes are expected to influence transport

pathways and distribution of anthropogenic pollution due to expected changes in the temperature regime

What do we propose to do?
Existing data should be used and new campaigns initiated to obtain relevant data in order to understand these processes better than we do today. Models are a climatologist's laboratory. High resolution models should be utilized to reproduce the observed processes in detail. Results from these models will then be used to get information on how to describe these processes in large scale climate models.

High latitudes will experience climate change strongest. At the same time these latitudes have large natural variability. It is therefore crucial that long time series from these areas are continued in order to detect possible climate change.

2.2 Arctic Cloud and Aerosol Properties and Climate Models

What is the problem?
In order to make reliable predictions of future climate and the fate of the polar ice cover there is an urgent need for improved understanding of cloud and aerosol properties required to enhance climate-modelling capabilities. The largest source of errors and uncertainties in current climate models is the treatment of clouds. Radiative energy transfer through clouds depends on cloud phase (liquid, ice or mixed), particle size and (ice) shape. Incorrect treatment of arctic clouds may introduce errors larger than 30% in the atmospheric radiative energy budget. Few measurements have been made of Arctic clouds. As a result the prevalent occurrence of mixed phase stratus clouds is poorly understood and inaccurately represented in climate models. Aerosols (inorganic and organic) play a vital role in transport of contaminants into the Arctic. However, little is known about the aerosol characterisation and composition in the Arctic atmosphere (selective transport + deposition)

What do we propose to do?
Extensive ground-based and in-situ measurements of arctic stratus clouds and aerosols are needed for improved understanding of cloud formation and dissipation processes and the impact of clouds on the radiation budget and climate. Improved ground-based instrumentation at Ny-Ålesund (35 GHz Radar, polarization LIDAR, and 183 MHz Microwave Radiometer) and in-situ measurements by tethered balloon and/or aircraft (possibly low-cost UAVs) are needed to characterize cloud, aerosol, and atmospheric properties. Measured cloud and aerosol properties will be used to provide more accurate and physically sound treatments of clouds in arctic climate models in order to improve their performance in general, and enhance their predictive capabilities in particular. They will also be used for development and testing of algorithms designed for remote sensing of atmospheric and surface properties from space in the polar regions.
Chemical characterisation of the organic aerosol fraction for both the water soluble as well as the water insoluble part is necessary. We plan to develop and optimise comprehensive analytical methods using LC/MS and other chromatographic methods.

2.3 Atmospheric chemistry

2.3.1 Greenhouse gas cycles

What is the problem?

Kyoto verification and basic research requires determination of regional fluxes of greenhouse gases. The Arctic needs particular attention because of its expected strong climatic response and sensitive reservoirs of carbon and potential rapid methane release. The climate sensitivity of the greenhouse gas fluxes and their implication as positive feedback mechanisms is a high priority item. Methods available to date are insufficient to give quantitative regional estimates mainly due to inadequate data and incomplete exploration of mechanisms.

What do we propose to do?

A tight grid of ground-based stations combined with new technology (balloon soundings for greenhouse gases), aircraft and remote sensing data are combined to give regional 3-dimensional concentration distributions for extended periods (the duration of IPY). By combining surface flux measurements, 3-D concentration fields with atmospheric models internal consistency of our knowledge is tested and builds a foundation for predictive skill regarding these fluxes under climate change.

2.3.2 Arctic contaminants

What is the problem?

Increased concentrations of anthropogenic contaminants in marine arctic ecosystems affect reproduction, immune system and general health in Arctic wildlife. There are several problems that need to be studied. During AMAP's 2nd phase one of the most spectacular results found was the Arctic Hg depletion phenomenon, where unreactive forms are transferred to reactive forms, which are deposited in the Arctic. While the existence of this ecologically important phenomenon in cold environments is now accepted by the scientific community, many uncertainties remain in our understanding.
In addition to this, based on new advanced analytical techniques, the presence of a number of new anthropogenic contaminants in the Arctic has been confirmed over the past years (e.g. perfluoro–alkylated substances, brominated flame retardants etc.)

What do we propose to do?

We will use a combination of analytical tools and modelling as well as retrospective analyses to evaluate long-range transport of pollution and deposition pathways dependent on climate related parameters (temperature, radiation, meteorology). We plan to study processes and total Hg input to the polar regions. We will carry out measurements campaigns from mobile (ships) and stationary stations.
By applying a combination of new, highly sensitive analytical techniques, methods for investigations of ecotoxicological effects as well as molecular modelling, these new emerging Arctic contaminants will be subject for thorough ecotoxicological evaluation.

2.3.3 Stratospheric ozone and related parameters

What is the problem?
Stratospheric water vapour has increased by about 1%/year during the last 20 years. Water vapour is considered the second most important component in the stratosphere after ozone. Water vapour is an important greenhouse gas and increased amounts of this gas will lead to lower temperatures in the stratosphere. More water vapour and lower temperatures will both lead to more frequent occurrence of polar stratospheric clouds. This will cause more loss of stratospheric ozone.

What do we propose to do?
There are very few measurements of stratospheric H_2O, and there is a need for observations in the polar regions. A bipolar study would give us new knowledge on similarities and differences between the Arctic and the Antarctic. We propose to launch balloons with precise frost point hygrometers from a few selected stations in both polar regions. These data will be compared to satellite observations.

2.4 Upper and middle polar atmosphere

What is the problem?
There is a need for a better understanding of how energy and momentum are transported from the Solar Wind and interplanetary space through the polar thermosphere to the middle and lower part of the atmosphere, and how the coupling between the regions can affect the climate system. Especially interesting areas to study are the role of aerosols, trace gases, and metallic layers.

What do we propose to do?
In addition to satellite measurements there is a need for measurements with:

- Rockets
- Lidar
- Ionosonde
- Radar
- Optics

IPY will give a unique opportunity to do magnetic conjugate studies between Svalbard and the Chinese station Zhongzhan in the Antarctic.
A lightweight, campaign-oriented instrumentation has been devised: The Mobile Rocket and Radar Observatory (MORRO). This small observatory could be placed on the ice in the Arctic together with other experiments.

PY will represent a unique opportunity to obtain simultaneous long time series of important geophysical parameters over a wide area in the Arctic region by operating all EISCAT IS- radars together with the existing and planned IS-radars in Greenland and at Resolute Bay and Alaska.

IPY would represent a unique opportunity to operate ALOMAR over extended periods together with a large suit of other ground based and rocket observations of the polar middle atmosphere.

Svalbard is a key location for detailed multi-instrument observations of Solar-Terrestrial interaction in the auroral cusp/cleft region. IPY will give unique opportunities to arrange multi- instrument campaigns in this field.

2.5 Weather forecasting

What is the problem?

Studies have shown that high impact weather frequently has its origin at high latitudes. These areas are among the least observed areas of the globe. We therefore have to draw attention to the importance of weather observations in the Arctic. Optimal use of observations for atmospheric modelling and weather forecasting rely on that these observations are available in real time and that they can be used on modern data assimilation systems. All kind of data is important, but high quality three-dimensional data is crucial.

What do we propose to do?

There is a need for enhanced observational campaigns in the Arctic and Antarctic during the IPY in order to demonstrate what can be achieved with a better observational coverage and to learn how this data should be used in an optimal way. The observational program on existing stations should be enhanced to include radiosondes where possible. Russian closed down stations should be opened. THORPEX-type observational campaigns with unmanned aircrafts and driftsondes (gondolas flying at fixed altitude) dropping radiosondes, should be launched. During an IPY the use of satellite data at high latitudes should be focused on. It is in particular important to distinguish between clouds and the underlying cold surface and the radiative properties of ice clouds. A network of ground based observations on the ice should be established.

3. Climate processes and effects – ice and ocean

Overarching scientific issues:

The role of the Poles in global change – climate processes and effects

"Aims at a capability for detecting and predicting climate change and effects on decadal to centennial time scales"

3.1 Theme 1: Understanding the energy balance of polar oceans

i) monitor ocean fluxes in and out of the Arctic Ocean (i.e. through the Fram-,
Bering-, and Nares Straits – Arctic Gateways)

ii) measure energy re-distribution internally in the Arctic Ocean and in the Southern Oceans

iii) observe ocean – sea ice – atmosphere exchange (e.g. albedo and freezing/melting processes)

3.2 Theme 2: Understanding the water balance

i) measure mass balance of terrestrial ice (i.e. arctic glaciers, Greenland and Antarctica) to improve estimates of current and future sea level change

ii) measure mass balance of marine ice and freshwater

- improve measurements of sea ice concentration and sea ice thickness ("a blue Arctic Ocean this century?")

- improve estimates of fresh water fluxes and its influence on thermohaline circulation and its potential for rapid climate change

Important tools to support campaign-based experiments ought to be co-ordinated use of information from satellites and the use of permanent and mobile installations (e.g. research stations, ships, aircrafts, buoys, floats, moorings).

Experiments should improve future long-term monitoring programmes and the parameterisation and performance of climate models, in particular GCM's.

4. Paleoclimate, geology and geophysics

In this area of research there are a number of truly first order scientific questions that has not been solved, and where a concerted international effort would make a large difference, by mobilizing the intellectual and logistical capacity that is required to solve them.

The main IPY activities would be a focussed field campaign to retrieve the material and in parallel provide model developments that both are required for subsequent research. The approach is interdisciplinary and well founded in the strategies of major international research programs.

The main overriding scientific theme:

The polar oceans´ influence on climate and climate change

This can be addressed by research on different timescales specified by the following key research questions, for which we propose specific IPY activities:

Key questions:

4.1. Ocean gateways – and the evolution of polar ocean connectivity

We do not know the timing and impacts of the process that connected the Arctic Ocean to the World Oceans. Much of the impacts of the opening of the Fram Strait to facilitate ocean exchange remain elusive at this point. We propose the following IPY activities.

- IODP – mission specific platform initiative
- Geodynamic modelling and climate modelling of gateways development and impacts.
- Potential areas: north of Yermak plateau, St. Anna trough
- Approached both by ocean drilling and long cores

4.2. Determine past modes of thermohaline circulation (THC) and the climate/dynamic thresholds activating modal shifts

Shifts in the modes of the THC are implicated as a key factor for abrupt climate changes, yet we do not know a number of fundamental aspects of these shifts. A breakthrough will require activities in both polar regions.
The THC influences:

- Meridional heat transport
- Ocean uptake of heat and CO_2 (including anthropogenic)

A. The role of Southern Ocean circulation changes in the global overturning system/meriodanal overturning.

- Antarctic Circumpolar Current variability
- Influence from the Antarctic on low latitude climate via the Antarctic Intermediate Water (AAIW)

B. The role of bouyancy forcing and freshwater fluxes in the northern latitudes.

- Did freshwater releases in/through the Arctic trigger THC changes?

For this key question we propose the following IPY activities.

- Piston/Calypso coring campaigns in the Pacific to Scotia/Weddell Seas. These will obtain marine records that complement ice-core records
- Piston/Calypso coring using joint Nordic icebreaker campaign in the Arctic.
- Onshore sites to complement offshore sites – Circum-arctic

Planning of the Southern Ocean activities are already well developed by the Images Southern Ocean working group, as a key activity of the Images program of PAGES (Past Global Changes) – IGBP.

4.3. Initiation and history of cryosphere and sea-ice cover and the question of warm Arctic

At present we do not know the timing of the initiation of the sea-ice and land ice in the Circum Arctic, nor its history and worldwide impacts. We know that the Arctic was ice-

free before, but not when and what characteristics it had. Obtaining this information is also important in view of a possible blue Arctic in this century.

We propose the following IPY activities.

- Via IODP activities and long cores retrieved from icebreakers, retrieve a sediment archive down to mid-Cenozoic times – on both sides of Fram Strait.
- Joint work on land and marine archives

In summary:
We have a number of 1. order outstanding scientific questions. But, we do not have the material to solve them. Current activities will not provide the critical mass to solve these key questions. The answer is to use IPY as a concerted campaign to acquire the necessary material. This material foundation will provide a long-term legacy for IPY.
The campaigns will be focused by international programmes, using latest coring techniques, geodynamic models, climate models, and knowledge of sedimentary archives.

Specific proposed activities:

- ODEN - IMAGES type coring in Arctic. A potential joint Nordic Initiative using icebreakers
- IODP – drilling in the Fram Strait Gateway and on both sides of it.
- Implementation of the IMAGES Southern Ocean plans to obtain material from the Pacific, Drake Passage and Scotia/Weddell Seas, using the French Marion Dufresne-Calypso coring facility
- Additional coring on possible NARE expedition

5. Observations and technology

One cannot discuss this issue without clarifying which scientific problems one is addressing. Therefore the group discussed 2 issues which both relate to climate and climate change, in particular to the role of the Arctic in this regard:

1) The role of ocean circulation (often narrowed down to, but not necessarily very precise: “Thermohaline Circulation”) in rapid climate change. This implies that scientific studies should address topics such as freshwater transports and budget, heat transports/fluxes, air-sea-ice processes (leads, polynyas, brine rejection, etc.) with focus on experimental work requiring dedicated IPY logistics
2) The role of the atmosphere (here including atmospheric circulation modes as well as atmospheric chemistry (clouds, climate gases)) in climate and climate change.

Focus on field experiments that can give IPY an identity and provide new data that can only be achieved through a co-ordinated international programme.

Why stress these issues during IPY?
The international flavour of IPY, and the political will to make IPY happen, gives one a chance for international collaboration around the circumference of the Arctic Ocean, i.e. it might be possible to make simultaneous measurements (of meteorological and environmental variables, atmospheric chemistry, biology, ice, sea level, hydrological parameters etc.) one couldn't make before. Thus, **making simultaneous, circum-Arctic measurements would be a "spectacular" aspect of IPY:**

The technical difficulties of making measurements at large regional scale in the Arctic Ocean proper are overwhelming. Overcoming them is prohibitively expensive. Again, the international flavour of IPY, and the political will to make IPY happen may be the only possible avenue. Thus, **simultaneous, regionally distributed, measurements of the ice, ocean and atmosphere in the Arctic Ocean proper would be a "spectacular" aspect of IPY.**

Our recommendation is to use the IPY as a vehicle to develop cost-effective automated systems with automated data transmission systems, so that observations of the Arctic in the future will be possible without always involving a set of ice breakers. .

This is an opportunity to push Norwegian technology, such as the ice buoys used in the International Arctic Buoy Programme. Advanced "IPY" buoys could be built and deployed, measuring a wide range of atmospheric, sea ice and ocean parameters, and transmitting dat a in real time.

The maybe most prominent change in observation techniques since the International Geophysical Year in 1957-58 is the wide use of satellite data, which especially in the polar regions provides an other dimension of data available. However, many of the satellite data algorithms are not optimised for the application to extreme environments, such as the polar regions, so that the data quality there often is not satisfactory. We, therefore, recommend using IPY as a vehicle for a comprehensive effort to improve data algorithms and data quality at high latitudes over the whole scope of observations where such an effort is needed (atmospheric, oceanic, cryospheric or biological). This should be followed by a comprehensive validation campaign in order to assess the data quality improvement achieved. Such a campaign should be the starting point of continuous validation programmes of key parameters, which by the satellite instrument community nowadays is regarded as necessary to secure the quality and thus the long-term utilisation of satellite data.

The motivation is that there will be several new satellites in operation by 2007-09 (CryoSat, GOCE, SMOS as well as continuation of current programmes) and scientific projects should be defined for utilization of the data from these satellites. With Kongsberg Satellite Services and its receiver station SvalSat, Norway should have specific interests in better utilisation of satellite data for the polar regions.

5.1 The role of ocean circulation in rapid climate change

The scientific issues were discussed in Group 3.
Approaches:

a*) Heat budget for the Arctic; quantify volume, heat and salt transport into and out of Arctic Ocean proper*
Warm Atlantic Water enters the Arctic west of Spitsbergen, and through the Barents Sea. The properties of neither throughflow are monitored on the Arctic side, partly for political reasons (Barents Sea, Russia), and partly for traditional reasons (West Spitsbergen, where the effort is applied to the Fram Strait section, which sees significant recirculation). Therefore we propose the use of a traditional bottom-anchored current meter/Upward-looking Sonar array north of Spitsbergen (done for 3 weeks 20 years ago) and in the St Anna Trough (done once 10 years ago), as well as the use of a glider (programmed, autonomously navigating ctd/current meter system) across the Barents Sea-Arctic Ocean entrance between Kvitøya and Franz Josef Land (never done).

b) Arctic heat budget in Arctic; fate of Atlantic Water.
After the Atlantic Water enters the Arctic Ocean it primarily circulates cyclonically along the boundary. It loses heat remarkably fast upwards and downwards in the water column, and sideways into the Arctic interior. The heat content of the Arctic Ocean varies with time, and its ability to store heat is neither understood nor monitored. The interaction of the oceanic heat with the very sensitive ice cover and the atmosphere above could be a key parameter for understanding rapid climate change.

Aim to: aim use automated technology as much as possible (cheaper): array of ice-anchored drifting buoys (as a technical extension of the International Environmental Buoy Programme http://iabp.apl.washington.edu/) with both met sensors, ice/snow sensors, and oceanographic sensors that can profile through the warm Atlantic layer. The development of these will be a key ingredient of an upcoming meeting on advances in Arctic technology (see attached, preliminary announcement).

Oceanographic observations of the internal ocean variability in the Arctic Ocean have mainly been collected in large Arctic field experiments and few fixed moorings in key locations eg. ASOF Arctic/Sub-arctic Ocean Fluxes. This provides datasets which is inhomogeneous and sparse in time and space. Based on these observations it is very difficult to draw any conclusion if the heat content of the Arctic Ocean is changing.

Subsurface observations in the ice-free parts of the world ocean are steadily improving by an increasing number of drifting profilers down to 1000-2000 m (Argo program). The profiler techniques can currently not be used for routine observations in the ice covered Arctic due to huge problems in under ice navigation and data transmission/retrieval.

One possible option to improve the spatial and temporal sampling in the Arctic Ocean is to develop an integrated acoustic underwater system which can provide

- accurate navigation of moving platforms
- data transmission/communication

This will increase the possibility of using free-drifting and floats and moored buoys systems close to real time in the Arctic. Furthermore, such a network of acoustic transceivers will also provide environmental observations such as

- synoptic basin wide integrated ocean temperature/current observations from acoustic thermometry/tomography
- changes in ice dynamics and seismic processes through ambient noise observations

It will be challenge to establish and integrated acoustic system which satisfies the science, navigation and communication requirements.

Navigation using underwater acoustic technology is a difficult topic to be solved. However, previously several products have been developed for naval operations such as float tracking and localisation of moving objects under water. These products will be essential in developing a future navigation system for the Arctic region. Underwater communication, using acoustics is challenging and will need more research and development within signal processing techniques.

Globally there have been more than 20 ocean acoustic tomography and thermometry experiments over the last 20 years in the world oceans including the Arctic Ocean. Stand-alone acoustic tomographic systems have been developed and successfully tested for long term monitoring of convection in the Greenland Sea, heat and mass transports through the Strait of Gibraltar and for observing the heat content across the Mediterranean Sea. In the ongoing Labrador Sea tomographic measurements have been carried out since 1997 observing the heat content and stratification changes resulting from the deep convection activity. Furthermore, acoustic thermometry has demonstrated its effectiveness for basin wide climate monitoring in the ATOC experiment in the Pacific Ocean. The Trans Arctic Acoustic Propagation Experiment (TAP) across the Arctic Ocean in 1994 revealed basin-scale warming of the intermediate layer of Atlantic water relative to climatology, which supported the earlier sparse observations of warming of this layer in certain regions of the Arctic Ocean. Numerical simulations of using acoustic monitoring of the Arctic Ocean Climate have been conducted in the previous EU project AMOC and in the Arctic Climate Observations using Underwater Sound (ACOUS) program. The results of the recent, 14-month long ACOUS experiment have proven the capability of acoustic observations to monitor remotely long-term temporal and large-scale spatial variations of the water temperature in the intermediate layer and the thermocline depth; in the deep Arctic Basin. In particular, the ACOUS measurements detected significant changes in the Atlantic water mass in the Nansen Basin north of the Franz Victory Strait that occurred in the second half of 1999, which was not observed with other oceanographic tools. According to the above the acoustic

observation techniques are starting to mature as an efficient tool to monitor the internal ocean variability of temperature and heat content covering the whole water column, from shallow to deep water layers.

Ambient noise is defined to be sound which is generated by many natural processes at or beneath the sea surface (rain, waves, ice floe collisions etc), turbulence in the water column or seismic activity at the sea floor. The ambient noise recorded at a location contains combined information of the environment in which it was generated and has propagated through. In open water ambient noise is used to monitor wind and rain. In the Arctic Ocean, interior and in the marginal ice zones, the ambient noise can be used to monitor ice interaction such as cracking, ridging and break up. A large amount of studies of ambient noise in the Arctic were carried out in the 80s and 90s. There are both economical and environmental benefits of using ambient noise instead of man made acoustic sources. Passive monitoring systems need only configurations of acoustic receivers which will be cheaper than systems involving intensive sources. Undoubtedly, another benefit of the use of natural ambient noise is that it generates no additional acoustic "pollution" which can disturb the marine environment. Main area of effort will be to learn more how to use these passive acoustic observations to monitor the dynamic processes in the Arctic Ocean.

By installing a set of three sound sources/receivers around the periphery of the Arctic Ocean and few separate receiver arrays within the Arctic Ocean one would facilitate

- a under-ice navigation/communication for sub-surface instruments, ,
- direct measurements of heat storage changes in the arctic through acoustic thermometry/tomography
- observation of changes in sea ice dynamics through acoustic ambient noise

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A subsurface sound source system for the Arctic would be yet another "spectacular" possibility for the IPY.

Furthermore; by implementing an acoustic observing network in the Arctic, and linking this network with existing monitoring systems and data assimilation techniques, it will be possible to improve the global ocean observing systems by filling one of the most pronounced and recognized data gap in the ocean climate observing system.

Observing the cryosphere

Is Arctic Sea ice thickness decreasing as rapidly as suggested by recent investigations? Some scientists claim that ice thickness may have decreased as much as 40 % over the last 4 decades. However, there are very few observations documenting this reduction, which might very well be an indication of ongoing global warming. Sea ice area and extent, which has been observed by passive microwave satellite data for more than 20 years, has decreased by about 3 % per decade in the Arctic indicating that the total volume of sea ice has been reduced. The multiyear fraction of the ice area has decreased much more, about 7 % per decade. The major unknown parameter is the ice thickness due to lack of systematic observations.

The European Space Agency is developing a new satellite, CRYOSAT, which will have sea ice thickness measurement as a main objective. CRYOSAT, scheduled for launch in 2004, will observe the surface height of glaciers and sea ice using a beam limited altimeter. For sea ice the principle is to observe freeboard height and translate this to ice thickness. Specific studies on this problem are urgently needed to validate if basin-scale thickness distributions can be derived from freeboard data provided by CRYOSAT.

It is therefore essential to develop and implement robust and cost-effective *in situ and non-space* measurement systems to be operated from different platforms such as automatic buoys, fixed-wing aircraft, helicopter and ice-going vessels.

We propose to use IPY to design, implement and demonstrate an array of automatic ice buoys in the central Arctic with more advanced instrumentation than the present IABP buoys. This array should drift for 2 – 3 years and send data in real-time, enabling real monitoring of the atmospheres, sea ice and ocean across the Arctic The buoy network should be specially designed to provide new data to establish the relations between ice freeboard and ice thickness for summer and winter conditions, which is needed to derive ice thickness from CRYOSAT data.

c) storage/release of freshwater/ice in Arctic.

Freshwater has been shown to be stored as liquid and sea ice on inter-annual time scales in the Arctic, in particular in the Beaufort Sea. When released, this freshwater provides a pulse that may shut down air-sea interaction in the Nordic Seas and in the North Atlantic. For instance, the dense water formation in the Labrador Sea is very sensitive to fresh water export in the East Greenland Current. The set of ice-anchored buoys described above should allow monitoring f freshwater and sea ice storage in the Arctic. In addition it is essential that ice and freshwater export is monitored along the coast of Greenland as well, in particular to settle how much is released in the Nordic Seas and how much in the sub-polar North Atlantic.

d) Thermohaline circulation in the Antarctic:
Weddell Sea: Ice shelf monitoring platform.

5.2 The role of the atmosphere (here including atmospheric circulation modes as well as atmospheric chemistry (clouds, climate gases)) in climate and global change.

The atmosphere is a major player in the global change processes which we are witnessing, and this is particularly valid in the polar regions. The polar regions have large
potential reservoirs of climate gasses such as methane, and nowhere else on the globe the radiation budget may be changed more dramatically via changes in surface reflectance (ice melting, snow coverage). Also the

coupling between the lowermost atmosphere and the middle atmosphere is very strong here, and the observed changes in the polar stratosphere may have a profound impact on the circulation patterns on the ground. All these processes have the potential of being important feedback mechanisms in the climate system, which are far from being represented adequately in today's climate models. Such changes may also have a strong impact on other processes, such as the transport of pollutants from lower latitudes to the polar regions and their accumulation in polar ecosystems. Investigations of such processes have been performed only at few hotspots; the big picture is very incomplete.

Therefore, it is of great importance to collect measurements of critical substances, especially those with a very inhomogeneous distribution, at a much tighter spatial grid than is the case today, e.g., aerosols, selected greenhouse gases and organic/inorganic pollutants. This is to be achieved by:

a) a circum-Arctic set of land stations covering the whole scope of substances regarded as important
-for Norway: establishment/upgrade of Arctic island stations;

b) observations of a limited set of parameters (technically less demanding) from mobile ocean platform(s).

c) dedicated process studies, preferably of interdisciplinary character, on campaign basis, eg. Ice breaker surveys. North Pole Observatory.

d) deployment of an array of ice buoys in the central Arctic with more advanced instrumentation than the present IABP buoys. This array should drift for 2 – 3 years and send data in real-time, enabling real monitoring of the atmospheres, sea ice and ocean across the Arctic.

6. Additional input

6.1 Biogeochemical activities in the IPY 2007-8

The Arctic and Antarctic Seas are important carbon sinks. Compared to the Arctic the Southern Ocean C sink is far smaller than expected from the concentrations of nitrate, phosphate, and silicate, which are the highest anywhere in the upper world ocean. This is a consequence of small primary production in the ice-free Southern Ocean, caused by strong iron and grazing control or in periods and light limitation. In the Arctic the C sink is determined by bottom water formation, a strong biological pump and cooling of surface waters over shallow shelves.

Carbon pumping carries CO_2-laden surface water towards the bottom. Primary production lowers fCO_2 and produces organic particulate matter, of which a fraction will sink, and Dissolved Organic Carbon (DOC), of which a fraction ultimately becomes refractory. In ice-filled waters and in and on the

underside of the sea ice, the iron control of primary production is relieved, resulting in higher production than in the high-nutrient-low chlorophyll water (HNLC) of the non-coastal waters of Antarctica.

Based upon an Arctic-Antarctic comparison, Norwegian carbon cycle research during IPY 2007-8 should be co-ordinated with studies of deep-water production and otherwise focus upon A) vertical export of biogenic matter, B) the upward transport of nutrients and C) the regulation of primary and bacterial production by physics, sea-ice, nutrients and grazing. Studies of the role of iron and other trace metals are essential for understanding how DOC and iron interact, keeping iron partly bio-available while, on the other hand, producing free radicals and superoxides that, together with UV radiation, can be harmful to life. The growth conditions for algae and bacteria in and on the under-side of sea ice should be compared to the HNLC waters and Arctic sea ice (which is very different) in order to identify how “ordinary” nutrient limitation is replaced by iron control. Vertical flux regulation in the twilight zone (i.e. upper 200 m) is crucial for the quantification of carbon sequestration, but in essence unknown except for certain regions in the Barents Sea.

Norway has wide expertise in modelling and the physical, chemical and biological aspects of oceanography that deal with the carbon cycle and the acclimation of marine life to global change. Considering that crucial processes are little known, Norwegian researchers, in addition to sampling of field data in the biogeochemically most active upper water layers and modelling, should carry out shipboard and laboratory experiments on phytoplankton, zooplankton and bacteria. The experiments should A) include studies of the impact of light, nutrients, iron and trace metals on the competition between different species (groups) of phytoplankton and bacterial communities, which have different impact on carbon recycling and pumping. B) they should focus on grazing by micro and meso/marcozooplankton. The data should also be used to model the impact of global change on cold-water organisms. Moreover, considering CO_2-dependent acidification of the upper ocean by perhaps 0.3 pH units within the year 2100, the behaviour of marine organisms and ecosystems exposed to elevated CO_2 concentrations and lowered pH should be studied both in the Antarctic and the Arctic.